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Year: 2011

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## Techniques for highlighting relief on orthoimagery

Bernabé-Poveda, M A ; Sánchez-Ortega, I ; Cöltekin, Arzu

**Abstract:** In cartographic products such as shaded relief maps or orthoimagery, the direction of illumination can cause a perceptual phenomenon called terrain reversal effect where the depressions appear as peaks and vice versa. This is the case for predominantly north-oriented shaded relief maps and geographic imagery in the northern hemisphere. The problem is a troubling one for distinguishing three-dimensional spatial relationships between the landforms, photo interpretation, and possibly for image classification tasks. Rotating the image or creating a negative of it seems to reverse the spatial relationships back to the intended representation, however these are poor solutions. The former discards the familiarity of the north-orientation and is prone to confuse the viewer, and latter modifies the color information in such a fundamental way that it is nearly impossible to tell the natural features apart. Currently there are only a few technical solutions that address this issue. With this paper, we contribute a range of techniques that explore the possibility of merging a perceptually-driven adjustment of a hill shading model with the orthoimagery to visualize the depth information in a perceptually correct manner.

DOI: <https://doi.org/10.1016/j.sbspro.2011.07.028>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-54240>

Journal Article

Published Version



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Originally published at:

Bernabé-Poveda, M A; Sánchez-Ortega, I; Cöltekin, Arzu (2011). Techniques for highlighting relief on orthoimagery. *Procedia - Social And Behavioral Sciences*, 21:346-352.

DOI: <https://doi.org/10.1016/j.sbspro.2011.07.028>

International Conference: Spatial Thinking and Geographic Information Sciences

## Techniques for highlighting relief on orthoimagery

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### Abstract

In cartographic products such as shaded relief maps or orthoimagery, the direction of illumination can cause a perceptual phenomenon called *terrain reversal effect* where the depressions appear as peaks and vice versa. This is the case for predominantly north-oriented shaded relief maps and geographic imagery in the northern hemisphere. The problem is a troubling one for distinguishing three-dimensional spatial relationships between the landforms, photo interpretation, and possibly for image classification tasks. Rotating the image or creating a negative of it seems to reverse the spatial relationships back to the intended representation, however these are poor solutions. The former discards the familiarity of the north-orientation and is prone to confuse the viewer, and latter modifies the color information in such a fundamental way that it is nearly impossible to tell the natural features apart. Currently there are only a few technical solutions that address this issue. With this paper, we contribute a range of techniques that explore the possibility of merging a perceptually-driven adjustment of a hill shading model with the orthoimagery to visualize the depth information in a perceptually correct manner.

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**Keywords:** Relief perception; orthophotos; aerial imagery; satellite imagery; highlighting; terrain reversal effect, relief inversion effect, false topographic perception phenomenon; photo interpretation

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### 1. Introduction

In aerial photography and satellite imagery, the direction of sunshine determines how hills are (high)lighted or shadowed. This may sound like stating the obvious but it is this natural relationship between the lighting and shadowing which leads to the perception of depth in essentially two-dimensional representations. However, in some parts of the Earth, e.g., in almost all of the Northern Hemisphere, this light and shadow relationship also produces the well known “terrain reversal effect” (e.g. [1], [2]), termed as “false topographic perception phenomenon” by Saraf et al. (2007) [3]. This effect can be found on current Internet services, such as on Virtual Globes and web map servers (WMS), and it gives the observer a reverse perception of the relief she or he sees, where peaks appear as depressions and

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depressions appear as peaks (Fig. 1). The phenomenon exists also on non-geographic spatial configurations, such as in perception of a ‘face’ (represented as a mask) as demonstrated in the well known ‘hollow mask illusion’ [4].

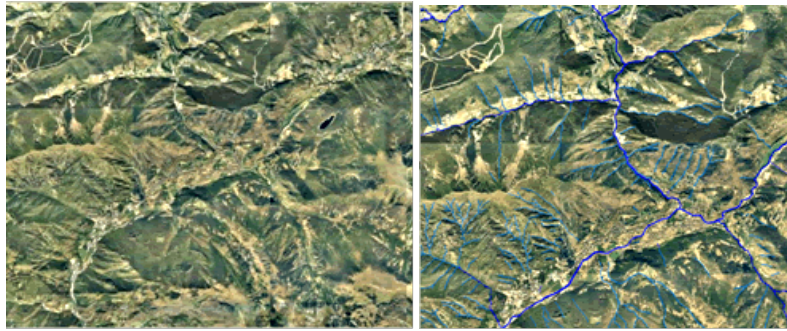


Fig. 1. Left: An image of Andorra as seen in <http://www.sigma.ad/sma/www/>, Right: with the hydrographic net [5]. In this picture many people perceive the terrain reversed, i.e. rivers seem to flow following ridges.

For tasks that require identifying the spatial relationships in three dimensional physical configuration of the Earth, such as photo-interpretation or image classification; it is necessary to design a model that helps to modify this reversed terrain perception. Illumination models used in hill shading do not always consider this impact, creating imperfect visual representations. Several options for modifying this illumination are proposed in this paper.

## 2. The problem and a theoretical solution

### 2.1. Direction of light

Most hill shading models use an assumed northwest light source, corresponding to upper left corner in traditional north oriented maps. This appears to be a very strong cartographic tradition, despite the fact that in the natural world this is rarely the direction of the sunlight [1] [6]. Patterson (2011) attributes this tradition to the dominant right handedness combined with the desk lights that are positioned to illuminate the paper from the left [6]. In the natural world, in the northern hemisphere, sun mostly illuminates the Earth from the south (Fig. 2), highlighting southern slopes and leaving northern slopes in shadow.

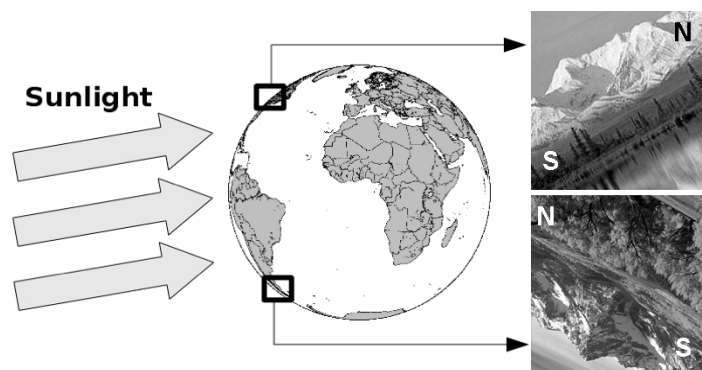


Fig. 2. The relative position of the sun and the earth creates a different illumination in the southern and northern hemispheres.

As mentioned in the previous section, the position of the light source and the north-orientation not only can lead to ambiguous or inverted perception of the three dimensional spatial features in relief maps, but also in orthoimages (aerial or satellite imagery). To create a non-ambiguous relief representation in an orthophoto (of a location in the northern hemisphere which is susceptible to this illusion), north-western slopes should be illuminated more, while south-eastern slopes should be shadowed. Creating an artificial hill shading model that takes perceptual parameters into account, and combining this model with the orthoimagery can be useful for adjusting the illumination in the scene. In such a scenario, flexibility to change the light direction can be useful to highlight particular terrain features [1]. For example, the artificial hill shading model can be created with predefined hill shading parameters; i.e. the traditional 315° azimuth and 45° altitude for an upper left lighting. Fig. 3 shows an original orthoimage (left) and the result when this image is integrated with the traditional 315° azimuth and 45° altitude artificial hill shading model (right).



Fig. 3. Left: An original orthoimage of Navarre, Spain (Northern Hemisphere). Right: the same image but transformed using a superimposed artificial hill shading model with 315° azimuth and 45° altitude for a top-left lighting.

Controlling and neutralizing the effect of the sunlight is desirable, however, sunlight is often not trivial to model. Effects such as the light scattering and radiometric correction play an important role [7] [8]. Even the epoch in which the photograph was taken has importance. For the sake of simplicity, we assume that the amount of sunlight during the image acquisition is equal to a hill shading model where the light source imitates the sun's angle.

## 2.2. Merging hill shading information into an orthophoto

Modern geographic information systems allow for complex mathematical manipulation of raster datasets [9]. Taking advantage of this, we propose merging the hill shading models with orthophotos to address the ambiguity of relief perception in orthophotos. While doing this, we must keep in mind that computerized hill shading models must have the same resolution and spatial reference as the orthophoto; otherwise interpolation is necessary for performing cell-by-cell manipulation. Also, dark pixels in the artificial hill shading model will make respective pixels in the orthophoto darker, and light pixels in the artificial hill shading model will make respective pixels in the orthophoto lighter. Vice versa is true for the natural hill shading model. In other words: if a pixel in the orthophoto has  $(r, g, b)$  as the values for its red, green and blue bands respectively; a pixel in the natural hill shading model has a value of  $h$ , and the one in the artificial hill shading model has a value of  $h'$ , then a function  $f(r, g, b, h, h') \rightarrow (r', g', b')$ , that complies with the next conditions, must be defined:



- If  $h_1 > h_2$ , then  $f(r, g, b, h_1, h')$  brighter than  $f(r, g, b, h_2, h')$  for every value of  $r, g, b, h'$
- If  $h_1 < h_2$ , then  $f(r, g, b, h_1, h')$  darker than  $f(r, g, b, h_2, h')$  for every value of  $r, g, b, h'$
- If  $h'_1 > h'_2$ , then  $f(r, g, b, h, h'_1)$  brighter than  $f(r, g, b, h, h'_2)$  for every value of  $r, g, b, h$
- If  $h'_1 < h'_2$ , then  $f(r, g, b, h, h'_1)$  darker than  $f(r, g, b, h, h'_2)$  for every value of  $r, g, b, h$
- A pixel  $(r_1, g_1, b_1)$  is brighter than  $(r_2, g_2, b_2)$  if  $r_1 > r_2$  and  $g_1 > g_2$  and  $b_1 > b_2$
- A pixel  $(r_1, g_1, b_1)$  is darker than  $(r_2, g_2, b_2)$  if  $r_1 < r_2$  and  $g_1 < g_2$  and  $b_1 < b_2$

There are several functions that comply with the conditions defined above and all of them make the relief more pronounced. However, the way they do (the method used) will have an impact on various qualities of the orthophoto, depending on how the colors are processed. For example, the highlighting effect can be made more pronounced (and noticeable) by changing the weight of  $h$  and  $h'$ .

### 3. Proposed techniques and example results

Difference between the natural and artificial hill shading models in northern hemisphere is much greater than in the southern hemisphere. Therefore we will use examples from the northern hemisphere.

#### 3.1. Drawing a pixel's value closer to white or black

This technique will draw the  $(r, g, b)$  values of a pixel towards white  $((1,1,1))$  or black  $((0,0,0))$  depending on the values of  $h$  and  $h'$ .

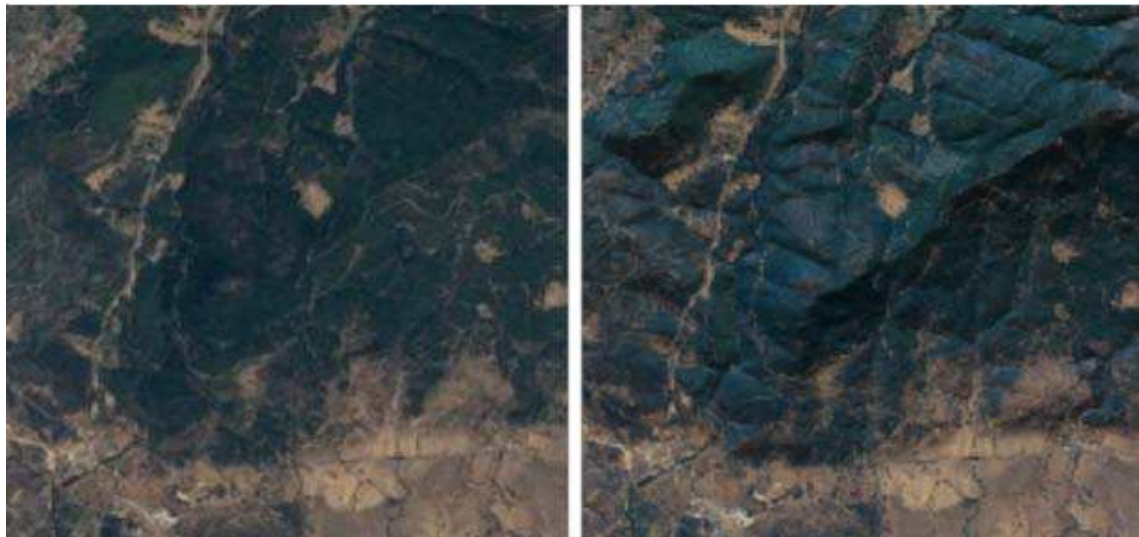


Fig. 4. Close-up of original (left) and processed (right) orthophoto with “whitened” and “blackened” pixels. Original image courtesy of the Instituto de Tecnologías Agrarias de Castilla y León.

The shift of all three channels towards 0 or 1 will be proportional: unless the result is either  $(0,0,0)$  or  $(1,1,1)$ , the proportions  $r/g$ ,  $g/b$  and  $r/b$  are to be preserved (ignoring degradation due to pixel depth). Fig. 4 shows an example of this approach.

### 3.2. Making pixels brighter or darker

Drawing the pixel values towards black or white distorts the color hue, and might produce an image which may seem artificial or exaggerated.



Fig. 5. Close-up of original (left) and processed (right) orthophoto preserving perceived color hue. Original image courtesy of the Instituto de Tecnologías Agrarias de Castilla y León.

A better solution would maintain the perceived color hue constant, and modify just the perceived color brightness. This can be achieved by working on well-known color spaces other than RGB [10], making algorithm do color space conversions internally. An example with a luminance and chrominance color space can be seen in Fig. 5.

### 3.3. Semitransparent hill shading overlays

If the original orthophoto cannot be processed, using semitransparent overlays (an image in an RGBA color space) is helpful. The value of the R, G and B channels corresponds to the value of the hill shading model, whereas the value of the alpha channel will be 0 (fully transparent) in flat areas (where the hill shading model is exactly mid-grey), and will raise up to 1 (fully opaque) in hilly areas (where the hill shading model goes towards either black or white). Then this RGBA image is overlaid on the orthophoto. While this technique offers some deployment advantages (e.g., ability to apply the same overlay to several sets of imagery, and turn it on and off in the map viewer), has the disadvantage that it does so by overlaying semi-transparent grey tones, so in the end this technique de-saturates the colors in the orthophoto (Fig. 6).

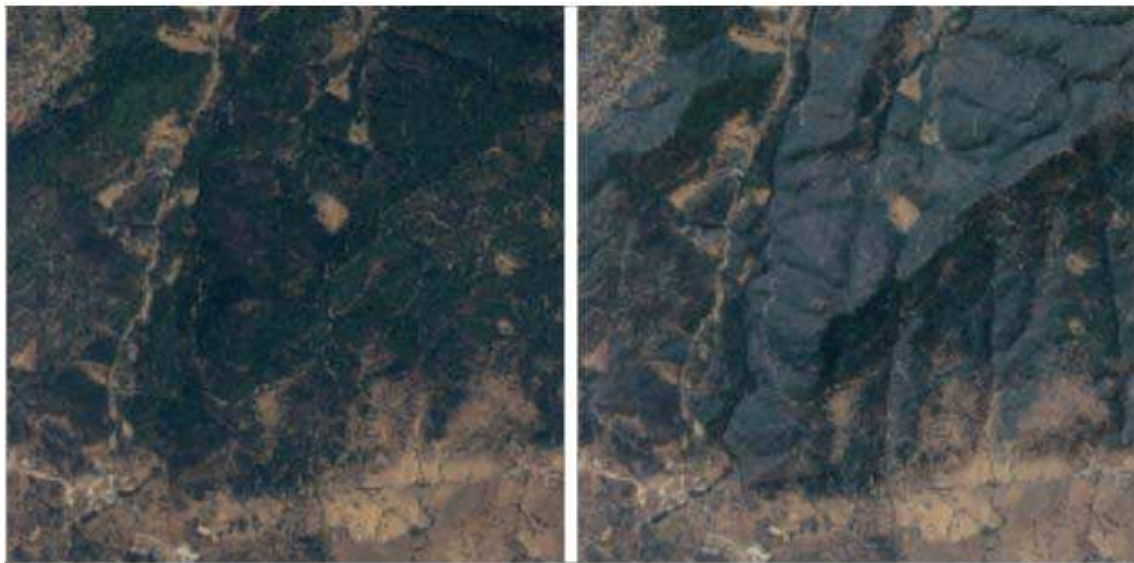


Fig. 6. Close-up of original (left) and processed (right) orthophoto with overlaid semitransparent hill shading model. Original image courtesy of the Instituto de Tecnologías Agrarias de Castilla y León.

#### 4. Discussion and future work

There is no easy way to determine which is the "best" method for overlaying hill shading information on top of an orthophoto, as relief perception is subjective and depends on the shape of the geographic features [1][5]. To address this consideration, a set of controlled experiments to measure user preferences may offer guidance as to which method yields a better perceptual interpretation. A possibility for a next step is to run a controlled experiment with eye movement recording integrated, which may allow additional perceptual and cognitive analyses [11][12]. Another downside to adding hill shading to an orthophoto is that some chromatic information will be invariably lost. However, we hypothesize that manipulating just the luminance of the orthophoto, a technique that does not de-saturate the colors, produces more natural-looking results. This hypothesis can also be potentially tested via user experiments. At the end of the day, however, it will be the cartographer's choice how much should the relief stand out, and what kind of information should be sacrificed. We contend that regardless of these current shortcomings to evaluate the results; the solutions we proposed in this paper offers flexibility to create alternative visual outputs; each correcting the terrain reversal effect, and may be helpful in further experiments.

#### Acknowledgements

Aerial photos and digital terrain models used in the figures are courtesy of the Instituto de Tecnologías Agrarias de Castilla y León. These freely available materials can be downloaded from their webpage at <http://www.itacyl.es/>. The open-source software libraries ImageMagick, Mapnik, GDAL/ORG and OpenLayers were used in the processing of the images. Special thanks to Colin Marquardt for his previous work on semitransparent relief overlays.

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